APPENDIX B
Risk Assessment Approach for Evaluating Potential Risks From Consuming Human Milk

INTRODUCTION

This appendix presents a standard approach for evaluating potential risks to infants from consumption of human milk. The approach was developed in conjunction with EPA Region 10 risk assessors. EPA Region 10 presented the approach in a memorandum dated _____ 2009. The following is consistent with the approach recommended by EPA and with Oregon Administrative Rules.

DEQ evaluated the feasibility of conducting a risk assessment based on exposure to human milk using EPA's *Human Health Risk Assessment Protocol for Hazard Waste Combustion Facilities*[1] (Combustion Guidance), *Exposure Factors Handbook*[2], *Child-Specific Exposure Factors Handbook*[3], and examples from other hazardous waste sites. We determined that it is feasible to include exposure to human milk in human health risk assessments, and that this is an important exposure pathway for bioaccumulating chemicals. Risk assessments for sites contaminated with polychlorinated biphenyls (PCBs), chlorinated dibenzenzo-p-dioxins (CDDs) and chlorinated dibenzofurans (CDFs), and/or DDT compounds (including DDE and DDD) shall include potential risks from the breast feeding pathway. Although DEQ considers these chemicals to be the most important contributors to risk from this pathway, we may require that you include other bioaccumulating chemicals released at the facility in the evaluation.

To assist risk assessors in incorporating the human milk consumption pathway into the human health risk assessment, we prepared this appendix to present the relevant exposure and risk equations, and exposure and toxicity parameters (summarized in Tables 1 and 2). We include example calculations using total PCB Aroclors to show how the various equations in EPA's combustion guidance can be modified to focus on the fish consumption, one of the most important exposure pathways for bioaccumulating chemicals. Actual risk assessments should include the exposure pathways relevant for the site. The risk assessments should also include all relevant chemicals, such as total PCBs (from Aroclors or congeners), 2,3,7,8-TCDD equivalents (from chlorinated dibenzo-*p*-dioxins, chlorinated dibenzofurans, and dioxin-like PCB congeners, evaluating each chemical class separately and collectively as the sum of all dioxin-like chemicals), and DDT and its degradation products.

We include relative risk ratios in this memorandum (Table 3) so that all the risk calculations for human milk ingestion do not need to be included in risk assessments. Instead, the potential risk to infants can be calculated based on the exposure to the mother, which should already be evaluated for relevant exposure pathways. This will simplify incorporation of the breast feeding pathway into the risk assessment.

Generally, risk assessments are limited to an evaluation of risk, and do not consider comparative risks or benefits. For example, eating fish is health beneficial compared with eating other animal protein. Public health agencies commonly address the health tradeoffs of eating contaminated fish, but the issue is not typically discussed in a Superfund risk assessment. For breast feeding, however, the benefits to infants are so substantial that we consider it appropriate to discuss the issue in the risk assessment

report. The Oregon Environmental Health Assessment Program (EHAP) has prepared a letter that presents the risks and benefits of consuming contaminated human milk. This letter has been reviewed by the Agency for Toxic Substances Control (ATSDR). DEQ recommends that information presented in Attachment 1 be included with risk assessments that include the breast feeding pathway.

PROPOSED RISK ASSESSMENT APPROACH

Exposure Assessment

We mainly relied on the equations presented in the EPA combustion guidance document[1], modified to make the equations no longer specific to dioxins or the inhalation pathway, and instead make them appropriate for human milk consumption based on fish consumption of the mother. The key concept is that the concentration of a chemical in milk can be calculated from the long-term body burden in the mother. This is consistent with the information presented in the Agency for Toxic Substances Disease Registry (ATSDR) *Toxicological Profile for Polychlorinated Biphenyls*[4].

Average Daily Dose to Mother

We start with the average daily intake of chemicals from fish consumption (modified from Table C-1-4 of the Combustion Guidance[1]):

$$ADD_{mother} = \frac{C_{fish} \times IR_{fish} \times CF \times F_{fish}}{BW_{af}}$$

Where:

ADD_{mother} = Average daily dose to mother (mg/kg/day)
C_{fish} = Chemical concentration in fish (assume 1 mg/kg for PCBs)
IR_{fish} = Ingestion rate of fish (standard default rate of 17.5 g/day)
CF = Conversion factor (0.001 kg/g)
F_{fish} = Fraction of fish contaminated (1)
BW_{af} = Body weight (66 kg for average adult female)

The ingestion rate used in the example is the default rate used by EPA in developing ambient water quality criteria. The fish consumption rate is an annualized rate (*i.e.*, it includes the assumption that fish are eaten throughout the year, so exposure frequency, exposure duration, and averaging time are not included in the equation). Loss of chemicals during cooking, which has been considered at other sites, is not included in EPA's Combustion Guidance. However, cooking loss can be addressed in the uncertainty section of a risk assessment. For body weight, we consider it appropriate to use the average female weight of 66 kg, rather than the guidance value of 70 kg (average adult weight).

For this example, the calculations are performed assuming a total PCB concentration of 1 mg/kg in whole-body tissue. This value is for illustration only, and to develop a relative risk ratio. An actual risk assessment should use chemical concentrations appropriate for the various species of fish sampled.

$$ADD_{mother} = 1 \text{ mg/kg} \times 17.5 \text{ g/day} \times 0.001 \text{ kg/g} \times 1 / 66 \text{ kg} = 0.000265 \text{ mg/kg/day}$$

The above equation is appropriate for evaluating non-carcinogenic effects to the mother, and for determining exposure to the breast-feeding infant because it covers the period of time where the mother's body burden is increasing to a steady state. For an excess lifetime cancer risk calculation for the mother, the equation would be modified to incorporate an exposure duration (typically 30 years) and an average time (lifetime of 70 years). The resulting average daily dose would be reduced to 0.43 times the ADD calculated above to a dose of 0.00011 mg/kg/day.

Chemical Concentration in Milkfat

EPA has found that dietary intake of PCBs during pregnancy and lactation is only weakly correlated with PCB concentrations in human milk. The more important determinant is long-term consumption of PCBs. The following equation is used to calculate the PCB concentration in milk fat.

$$C_{milkfat} = \frac{ADD_{mother} \times h \times f_1}{\ln(2) \times f_2}$$

Where:

$C_{milkfat}$ = PCB concentration in milkfat (mg/kg-lipid)
ADD_{mother} = Average daily dose to mother (mg/kg/day)
h = Half-life of PCB (7 years = 2555 days)
f_1 = Fraction of ingested PCB stored in fat (0.9)
f_2 = Fraction of mother's weight that is fat (0.3 kg-lipidBW/kg-totalBW)

$$C_{milkfat} = \frac{0.000265 \text{ mg/kg-totalBW/day} \times 2555 \text{ days} \times 0.9}{0.693 \times 0.3 \text{ (kg-lipidBW/kg-totalBW)}}$$

$$= 2.9 \text{ mg/kg-lipid}$$

The equation was modified from Table C-3-1 of the Combustion Guidance[1], and is consistent with equations 1 through 3(b) in Section 3.4.4.2 of the ATSDR *Toxicological Profile*[5]. The equation is for steady-state conditions, because we assume that maternal intake occurs over a time-period greater than the PCB half-life of 7 years. We also assume that PCB concentrations in human milk reflect the maternal body burden. For a derivation of the equation for $C_{milkfat}$, see Attachment 2.

Average Daily Dose for Carcinogens

Average daily doses to the infant are calculated separately for carcinogenic and noncarcinogenic effects. For carcinogenic effects, the average daily dose is the following (modified from Table C-3-2 of the Combustion Guidance[1]):

$$ADD_{ca\text{-}infant} = \frac{C_{milkfat} \times IRM_{adj} \times f_3 \times f_4 \times f_5 \times ED_i \times EF_i}{AT_c}$$

Where:

$ADD_{ca\text{-}infant}$ = Average daily dose for breast-feeding infant (mg/kg/day)
$C_{milkfat}$ = Concentration of chemical in milk fat (mg/kg-lipid)
IRM_{adj} = Age-adjusted ingestion rate of human milk (0.125 kg milk/kg BW/day)
f_3 = Fraction of human milk that is fat (0.04)
f_4 = Fraction of ingested PCB that is absorbed (0.9)

f_5 = Average fraction of initial chemical concentration present in human milk during one year of breast feeding (0.55)
ED_i = Exposure duration of breast-feeding infant (1 year)
EF_i = Exposure frequency of breast-feeding infant (365 days/year)
AT_c = Averaging time – carcinogen (70 years x 365 days/year)

IRM_{adj} was obtained from EPA's *Child-Specific Exposure Factors Handbook*[3] (EPA 2008). Table 15-1 of the guidance provides mean and upper percentile (two standard deviations above mean) dose values (ml milk per kg body weight per day) for the following age groups:

Birth to 0.25 years – mean 150 ml/kg/day, upper percentile 220 ml/kg/day
0.25 to 0.50 years – mean 140 ml/kg/day, upper percentile 190 ml/kg/day
0.50 to 0.75 years – mean 110 ml/kg/day, upper percentile 150 ml/kg/day
0.75 to 1.0 years – mean 83 ml/kg/day, upper percentile 130 ml/kg/day

Mean values are used in this evaluation. The arithmetic mean for one year of exposure is 120 ml/kg/day. Using a density of 1.03 g/ml for human milk[3], the resulting average age-adjusted ingestion rate is 125 mg/kg/day, or 0.125 kg/kg/day. This value is used for IRM_{adj}.

We looked at the reduction in body burden of PCBs in the mother during one year of breast feeding to develop a value for f_5. This factor is not included in EPA guidance, but we determined that it was reasonable to consider the known loss of mass during breast feeding. Our derivation of a value of 0.55 for f_5 is provided in Attachment 2.

We compared this value with one calculated using another approach. Some researchers have determined that there will be a 20 percent reduction of PCBs in the mother every three months[5]. Over a year, this would correspond to a reduction to $(1 - 0.2)^4 = 0.4$. The PCB mass will be reduced to 40 percent of the original amount after one year. At one-half year, the reduction is to $(1 - 0.2)^2 = 0.6$. This value is consistent with our decision to use a value of 0.55 (55 percent of the original amount) to approximate the typical chemical mass (and concentration) over the course of one year.

With all the parameter values selected, we can now calculate $ADD_{ca\text{-}infant}$ as:

$$ADD_{ca\text{-}infant} = \frac{2.9 \text{ mg/kg-lipid} \times 0.125 \text{ kg/kg/day} \times 0.04 \times 0.9 \times 0.6 \times 1 \text{ yr} \times 365 \text{ day/yr}}{70 \text{ yr} \times 365 \text{ day/yr}}$$

$$= 0.00019 \text{ mg/kg/day}$$

Average Daily Dose for Non-carcinogens

For non-cancer effects, the average daily dose is the following (modified from Table C-3-2 of the Combustion Guidance[1]):

$$ADD_{nc\text{-}infant} = \frac{C_{milkfat} \times IRM_{adj} \times f_3 \times f_4 \times f_5 \times ED_i \times EF_i}{AT_{nc}}$$

Where:

$ADD_{nc\text{-}infant}$ = Average daily dose for breast-feeding infant (mg/kg/day)
$C_{milkfat}$ = Concentration of chemical in milk fat (mg/kg-lipid)
IRM_{adj} = Age-adjusted human milk ingestion rate (125 kg milk/kg BW/day)
f_3 = Fraction of human milk that is fat (0.04 kg-lipid/kg-milk)
f_4 = Fraction of ingested PCB that is absorbed (0.9)
f_5 = Average fraction of initial chemical concentration present in human milk during one year of breast feeding (0.55)
ED_i = Exposure duration of breast-feeding infant (1 year)
EF_i = Exposure frequency of breast-feeding infant (365 days/year)
AT_{nc} = Averaging time – non-carcinogen (= ED_i x EF_i)

IRM_{adj} was calculated above.

$$ADD_{nc\text{-}infant} = \frac{2.9 \text{ mg/kg-lipid} \times 0.125 \text{ kg/kg/day} \times 0.04 \text{ kg-lipid/kg-milk} \times 0.9 \times 0.6 \times 1 \text{ yr} \times 365 \text{ day/yr}}{1 \text{ yr} \times 365 \text{ day/yr}}$$

$$= 0.013 \text{ mg/kg/day}$$

Toxicity Assessment

EPA's hierarchy for selecting toxicity factors is to first obtain factors from EPA's Integrated Risk Information System (IRIS). The cancer slope factor presented in IRIS is 2 $(mg/kg/day)^{-1}$. This value is applied to total PCBs.

The RfD for PCBs in IRIS is 2 x 10^{-5} mg/kg/day for chronic exposure (7 years to lifetime). There is no RfD for subchronic exposure in IRIS. Following EPA's hierarchy for toxicity values, the next source for a subchronic RfD is ATSDR. The ATSDR minimal risk level (MRL, comparable to an RfD) is 3 x 10^{-5} mg/kg/day for intermediate-duration (subchronic) oral exposure to PCBs. ATSDR defines intermediate-duration exposure as two weeks to one year. The intermediate-duration MRL was derived from a study on monkeys that approximated exposure during breastfeeding using a mixture of PCB congeners typically found in human milk. For this reason, it is a better indicator of toxicity than the chronic RfD (which is equal to the chronic MRL).

Table 1 provides the slope factors, chronic reference doses, and where available, subchronic reference doses for bioaccumulating chemicals.

Risk Characterization

Calculated Cancer Risk to Infants

Using the standard risk characterization equations, excess lifetime cancer risk and non-cancer hazards are calculated separately. Excess lifetime cancer risk is approximated by:

$$ELCR_{infant} = ADD_{ca\text{-}infant} \times SF_o$$

Where:
$ELCR_{infant}$ = Excess lifetime cancer risk to infant from breast feeding
$ADD_{ca\text{-}nfant}$ = Average daily dose for breast-feeding infant (mg/kg/day)
SF_o = Cancer slope factor – oral [2 $(mg/kg/day)^{-1}$ for total PCBs]

$$ELCR_{infant} = 0.00011 \text{ mg/kg/day} \times 2 \text{ (mg/kg/day)}^{-1} = 2 \times 10^{-4}$$

Calculated Non-Cancer Risk to Infants

The non-cancer hazard quotient is:

$$HQ_{infant} = \frac{ADD_{infant}}{RfD}$$

Where:
HQ_{infant} = Hazard quotient for breast-feeding infant
RfD = Non-cancer reference dose (3×10^{-5} mg/kg/day for total PCBs)

Using the intermediate-duration MRL, the calculated hazard quotient is:

$$HQ_{infant} = 0.0078 \text{ mg/kg/day} / 3 \times 10^{-5} \text{ mg/kg/day} = 260$$

Comparative Risk

For comparison, the calculated risks to the mother given the exposure assumptions are the following. For carcinogenic effects, using the long-term ADD and the oral slope factor:

$$ELCR_{mother} = 0.00012 \text{ mg/kg/day} \times 2 \text{ (mg/kg/day)}^{-1} = 2 \times 10^{-4}$$

For noncarcinogenic effects, using ADD without factoring in exposure duration and frequency, and averaging time, and using the chronic reference dose:

$$HQ_{mother} = 0.00027 \text{ mg/kg/day} / 2 \times 10^{-5} \text{ mg/kg/day} = 13$$

The relative ratios of risk to the infant compared with risk to the mother are the following:

$$\text{Cancer Relative Risk Ratio} = ELCR_{infant} / ELCR_{mother} = 2 \times 10^{-4} / 2 \times 10^{-4} = 1$$

$$\text{Noncancer Relative Risk Ratio} = HQ_{infant} / HQ_{mother} = 260 / 13 = 20$$

This evaluation shows that the breast-feeding infant's excess lifetime cancer risk is the same as the mother's. Also, the non-cancer hazard quotient to the infant is 20 times greater than the hazard quotient to the mother for PCB exposure. Although the example was performed using the fish ingestion pathway, **this result is independent of the exposure pathway or dose to the mother.** For PCBs, regardless of the exposure pathway to the mother or the dose, the excess lifetime cancer risk to the infant will always be equal to the risk to the mother, and the hazard quotient to the infant will always be 20 times the hazard quotient to the mother. This assumes that the conditions used to derive the default values are met; for instance, that the dose to the mother occurs for a long enough time relative to the metabolic half-life so that a steady-state condition is established. The relative risk ratios are dependent on the metabolic half-life of the compound, and the difference between the subchronic and chronic reference doses. At a half-life greater than 90 days, the exposure to the infant will be greater than the exposure to the mother.

A relative risk ratio of 20 for PCBs is not unexpected. This is based on a dose to the infant 30 times the dose to the mother. Other estimates are that the PCB dose to the infant is 50 times the dose to the mother[5], so our calculated results are consistent with empirical studies.

Table 3 provides a summary of the relative risk ratios for infant/mother for the major bioaccumulating chemicals. This provides a convenient method of including a breast-feeding pathway evaluation in risk assessments without having to perform the intermediate calculations. For any exposure pathway in a risk assessment where girls/women are exposed to bioaccumulating chemicals, the risk to infants from future breastfeeding can be calculated by multiplying the calculated excess lifetime cancer risk or hazard quotient by the factors shown in Table 3. Example calculations are shown in Table 4.

Comparison of Calculated Risks with Acceptable Levels

Using the approach presented in this memorandum, the excess lifetime cancer risk is approximately 2×10^{-4} for an infant consuming total PCBs in human milk for one year. This is substantially above the acceptable excess lifetime cancer risk of to 1×10^{-6}.

For non-cancer effects of PCB exposure, the calculated hazard quotient is 260. For hazard quotients above 1, unacceptable exposures may be occurring and there may be concern for potential non-cancer effects. Generally, the greater the magnitude of the hazard quotient above 1, the greater the level of concern for non-cancer health effects.

The calculated cancer risks and non-cancer hazards are based on a total PCB concentration in whole-body resident fish composites of 1 mg/kg. Although this concentration was used as a convenient value to demonstrate the calculations, it is within the range of total PCBs measured in resident fish tissue at Oregon sites. Because the calculated excess lifetime cancer risk and hazard quotient are considerably above acceptable levels, we conclude that infant exposure to chemicals in human milk will be an important pathway for sites contaminated with bioaccumulating chemicals.

UNCERTAINTY EVALUATION

Following standard guidance, the risk assessment for this pathway should include an evaluation of the associated uncertainties. During our evaluation of this pathway, we considered the following.

Exposure Assessment

The only exposure to infants evaluated was consumption of human milk. We did not consider other potential exposure routes, such as transplacental transfer of PCBs from mother to fetus during pregnancy.

The equation for the concentration of chemical in milt fat (Cmilkfat) assumes that intake to the mother has occurred for a period of time long enough relative to the half-life of the chemical that steady-state conditions are reached. For chemicals such as PCBs or CDDs/CDFs with half-lives on the order of 7 years, approximately 90 percent of steady-

state concentration is reached after 21 years of exposure to the mother (3 half-lives). If the mother is exposed for only 7 years prior to breast feeding, the concentration of chemical in milkfat will be only one-half the concentration calculated for steady-state conditions, and risks calculated using the steady-state equation will be overestimated by a factor of 2. The risk would still exceed the acceptable risk levels for both carcinogenic and non-carcinogenic effects.

ATSDR considers exposure of one year or more to be chronic exposure. However, EPA's Superfund program defines seven years or more as chronic exposure[6].

Toxicity Assessment

The ATSDR intermediate-duration MRL was derived from a study on monkeys that approximated exposure during breastfeeding using a mixture of PCB congeners typically found in human milk. The uncertainty factors were LOAEL to NOAEL conversion (10), sensitive members (10), and interspecies extrapolation (3), for a total of 300.

The chronic PCB RfD is also based on LOAELs developed from studies on monkeys. The health effects included inflammation of glands in the eye, distorted growth of finger and toe nails, and decreased antibody responses. The uncertainty factors used in the derivation of the human health RfD total 300, applied to an animal LOAEL of 0.005 mg/kg/day.

If a chronic RfD is used instead of a subchronic RfD, another uncertainty is the application of the RfD to one year of exposure, rather than long-term (lifetime) exposure. EPA's Superfund guidance defines chronic exposure as that between seven years and a lifetime. However, in its Combustion Guidance[1], EPA considered it appropriate to apply the chronic RfD to one year of exposure to human milk, at least for screening purposes. Application of the chronic RfD to one year of exposure may also be appropriate considering the potential sensitivity of infants to adverse health effects.

Risk Characterization

Using the chronic RfD for PCBs instead of the intermediate duration MRL, the calculated hazard quotient is:

$$HQ_{infant} = 0.0078 \text{ mg/kg/day} / 2 \times 10^{-5} \text{ mg/kg/day} = 390$$

This HQ is 1.5 times the subchronic HQ of 260.

Body Burden Reductions

Incorporation of body burden reduction during a year of breast feeding was included in the example evaluation of PCBs for the first infant that is breast-fed. For additional infants that are breast-fed by the same woman, the mother's body burden will be reduced to about 40 percent of the body burden prior to the previous breast-fed child.

Relative Exposure

EPA has considered presenting the potential risks from human milk consumption as a ratio to background risk rather than as an excess lifetime cancer risk or hazard quotient.

Background total PCB concentrations reported in the literature include 0.27 mg/kg-lipid in milk[7], 0.32 mg/kg-lipid[8], and 0.38 mg/kg-lipid[9]. Using the assumed total PCB concentration of 1 mg/kg in fish tissue and the assumed fish consumption rate, the calculated total PCB concentration in human milk is 2.9 mg/kg-lipid. As an alternative presentation of risk in the uncertainty section, this result can be discussed as corresponding to a risk approximately 8 to 11 times that of the background concentration.

Fish Advisories

DEQ is aware that in some major rivers, consumption of resident fish by lactating mothers is already discouraged by fish advisories. For example, the Oregon Department of Human Services (DHS) advisory for PCBs in the Willamette River states that:

> Women of childbearing age, particularly pregnant or breastfeeding women, children and people with weak immune systems, thyroid or liver problems, should avoid eating resident fish from Portland Harbor, especially carp, bass and catfish.

For this reason, there may currently be limited infant exposure to human milk contaminated as a result of consumption of resident fish in the lower Willamette River. In addition, DHS advice on preparing fish for consumption, including removing fat from fillets (rather than consuming whole-body fish), could substantially lower risks to fish consumers, and also subsequently to breast-feeding infants. However, the results presented here appear to quantitatively support the advisory, and indicate that there are potentially significant unacceptable risks by the breast-feeding pathway.

HEALTH CONSULTATION ON BREAST-FEEDING PATHWAY

EPA asked the Oregon Environmental Health Assessment Program (EHAP, formerly SHINE) to develop recommendations on how to address the potential health risks for infants exposed to PCBs in human milk in the context of the many health benefits of breast feeding. EHAP's evaluation and recommendations were reviewed by ATSDR, and are included in Attachment 1.

ENDNOTES

[1] U. S. EPA. *Human Health Risk Assessment Protocol for Hazard Waste Combustion Facilities.* (EPA 530-R-05-006, September 2005.
[2] U.S. EPA. *Exposure Factors Handbook.* National Center for Environmental Assessment, Office of Research and Development. August 1997.
[3] U.S. EPA. *Child-Specific Exposure Factors Handbook.* National Center for Environmental Assessment, Office of Research and Development. EPA-600-P-00-002B, Interim Report. September 2002.
[4] Agency for Toxic Substances and Disease Registry (ATSDR). *Toxicological Profile for Polychlorinated Biphenyls* (Update, November 2000).
[5] Svati Patandin, Pieter C. Dagnelie, Paul G.H. Mulder, Eline Op de Coul, Juul E. van der Veen, Nynke Weisglas-Kuperus, and Pieter J.J. Sauer. Dietary Exposure to Polychlorinated Biphenyls and Dioxins from Infancy Until Adulthood: A Comparison Between Breast-feeding, Toddler, and Long-term Exposure. *Environ Health Perspect* 107:45-51 (1999).
[6] U.S. EPA. *Risk Assessment Guidance for Superfund*. Volume 1. Human Health Evaluation Manual (Part A). Interim Final. (EPA 540-1-89-002). December 1989.
[7] Greizerstein, H.B., C. Stinson, P. Mendola, G.M. Buck, P.J. Kostyniak, and J.E. Vena. 1999. Comparison of PCB congeners and pesticide levels between serum and milk from lactating women. *Environ. Res.* 80(3):280-6.
[8] Korrick, S. and L. Altschul. 1998. High breast milk levels of polychlorinated biphenyls (PCBs) among four women living adjacent to a PCB-contaminated waste site. E*nviron. Health Perspect.* 34 106:513.
[9] Noren, K. and D. Meironyte. 2000. Certain organochlorine and organobromine contaminants in Swedish human milk in perspective of past 20-30 years. *Chemosphere* 40:1111-23.

Table 1
Half-lives and Toxicity Values for Bioaccumulating Chemicals

Chemical	Half-life (days)	Oral RfDsubchronic (mg/kg/day)	Oral RfDchronic (mg/kg/day)	Oral Slope Factor $(mg/kg/day)^{-1}$
CDDs/CDFs TEQ	2550	-	1×10^{-9}	1.3×10^{5}
DDD	120	-	-	0.24
DDE	120	-	-	0.34
DDT	120	-	5.0×10^{-4}	0.34
Total PCB	2550	3×10^{-5}	2×10^{-5}	2
PCB TEQ	2550	-	1×10^{-9}	1.3×10^{5}

Notes:
Source of half-lives:
Source of reference doses (RfDs):
Source of oral slope factors (SFo):

Table 2
Parameters for Evaluation of Risk from Consuming Human Milk

Parameter	Units	Description	Value[a]	Source
ADD_{mother}	mg/kg/day	Average daily dose to mother	Calculated	-
$ADD_{ca\text{-}child}$	mg/kg/day	Average daily dose to child (cancer)	Calculated	-
$ADD_{nc\text{-}child}$	mg/kg/day	Average daily dose to child (non-cancer)	Calculated	-
C_{fish}	mg/kg	Chemical concentration in fish	Calculated from site data. Assume 1 for example.	-
IR_{fish}	g/day	Ingestion rate of fish	17.5 for recreational fishers[b]	
IRM_{adj}	kg milk/ kg BW/day	Age-adjusted human milk ingestion rate calculated by averaging the following factors:	125	
		Birth to <3 months =	150 ml/kg/day	
		3 months to <6 months =	140 ml/kg/day	
		6 months to <9 months =	110 ml/kg/day	
		9 months to 12 months =	83 ml/kg/day	
		Density of human milk =	1.03 g/ml	
CF	kg/g	Conversion factor	0.001	
F_{fish}	unitless	Fraction of fish contaminated	1	
BW_{af}	kg	Body weight of adult female	66[c]	
BW_i	Kg	Body weight of infant	Incorporated into IRM	
$C_{milkfat}$	mg/kg-lipid	Concentration in milkfat	Calculated	-
h	days	Half-life of chemical	Chemical-specific	
f_1	unitless	Fraction of ingested chemical stored in fat	0.9 for PCBs	
f_2	unitless	Fraction of mother's weight that is fat	0.3	
f_3	unitless	Fraction of human milk that is fat	0.04	
f_4	unitless	Fraction of ingested chemical that is absorbed	0.9	
f_5	unitless	Average fraction of initial chemical concentration present in human milk during breast feeding	0.55	Calculated in Attachment 2

Table 2
Parameters for Evaluation of Risk from Consuming Human Milk

Parameter	Units	Description	Value[a]	Source
ED_c	year	Exposure duration of breast-feeding child	1	
EF_c	days/year	Exposure frequency of breast-feeding child	365 days/year	
AT_c	days	Averaging time – carcinogen	25550 (70 years)[d]	
AT_{nc}	days	Averaging time – non-carcinogen	= ED x EF	
$ELCR_{child}$	risk	Excess lifetime cancer risk	Calculated	
HQ_{child}	hazard	Hazard quotient	Calculated	
SF_o	$(mg/kg/day)^{-1}$	Cancer slope factor – oral	Table 1	
RfD	(mg/kg/day)	Reference dose (chronic)	Table 1	
MRL	(mg/kg/day)	Minimal risk level (intermediate duration)	Table 1	

Notes:

a) Exposure assumptions taken from *Human Health Risk Assessment Protocol for Hazard Waste Combustion Facilities* (EPA 530-R-05-006, September 2005), except as noted.
b) Used by EPA in developing ambient water quality criteria.
c) EPA combustion facilities guidance uses 70 kg (average weight of male and female adults).
d) EPA combustion facilities guidance is to use 1 year. We considered this too conservative, and used the lifetime AT_c value typically used at Superfund sites.

Table 3
Default Ratios for Calculating Human Milk Consumption Risks Based on Risks Calculated for Exposure to the Mother

Chemical	Ratio to Convert Chronic HQ for Mother to Subchronic HQ for Infant	Ratio to Convert ELCR for Mother to ELCR for Infant
CDDs/CDFs	**1.5**	**1.0**
DDT	**1.4**	**0.05**
Total PCB	**20**	**1.0**
PCB TEQ	**1.5**	**1.0**

Notes:
HQ = hazard quotient
ELCR = excess lifetime cancer risk
CDD = chlorinated dibenzo-*p*-dioxin
CDF = chlorinated dibenzofuran
DDT = dichlorodiphenyltrichloroethane
PCB = polychlorinated biphenyl
TEQ = 2,3,7,8-tetrachlorodibenzo-*p*-dioxin toxicity equivalent

Table 4
Example Calculation of Human Milk Consumption Risks Based on Risks Calculated for Exposure to the Mother

	Hazard Quotient		Excess Lifetime Cancer Risk	
Chemical	**Adult**	**Infant[a]**	**Adult**	**Infant[a]**
Soil ingestion exposure pathway				
Arsenic	0.13	-	2×10^{-6}	-
Total PCB	0.38	7.5	7×10^{-6}	7×10^{-6}
PCB TEQ	-	-	5×10^{-6}	5×10^{-6}
CDD/CDF TEQ	-	-	1×10^{-6}	1×10^{-6}
Total TEQ	-	-	6×10^{-6}	6×10^{-6}
Total	**0.51**	**7.5**	**2×10^{-5}**	**1×10^{-5}**
Fish ingestion exposure pathway				
Total PCB	13	260	2×10^{-4}	2×10^{-4}
PCB TEQ	-	-	2×10^{-4}	2×10^{-4}
CDD/CDF TEQ	-	-	8×10^{-5}	8×10^{-5}
Total TEQ	-	-	3×10^{-4}	3×10^{-5}
Total	**13**	**260**	**5×10^{-4}**	**5×10^{-4}**
Total for all exposure pathways				
Total	**14**	**268**	**5×10^{-4}**	**5×10^{-4}**

Notes
Calculated using infant/mother risk ratios shown in Table 3.

Attachment 1

PCBs in Breast Milk at Portland Harbor

Letter from
Oregon Department of Human Services, Public Health Division
to
U.S. Environmental Protection Agency, Region 10
16 September 2008

Attachment 2

Steady-State Chemical Concentrations in Milkfat and Loses During Breast Feeding

The EPA combustion facility guidance document[1] and ATSDR's Toxicological Profile[2] do not elaborate on the derivation of the equation for calculation of chemicals present in milkfat. The main EPA reference for the equation is Allan Smith's evaluation of infant exposure to chlorinated dibenzodioxins and chlorinated dibenzofurans in human milk[3]. In this attachment, we first explicitly derive the steady-state equation used to approximate chemical concentrations in maternal body fat, which is assumed to be equivalent to the concentration in human milk. Then we consider chemical mass loses in the mother as a result of breast feeding.

Steady-State Chemical Concentration in Milkfat

The chemical body burden in the mother is calculated assuming first-order kinetics:

$$B_t = B_0 \, e^{-kt}$$

Where:
t = Time period (years)
B_t = Body burden at time t (mg)
B_0 = Body burden at time $t = 0$ (mg)
k = Rate constant = ln(2) / h (days^{-1})
h = Half life of chemical in body (days)

Using this standard approach, the maternal daily chemical intake, m (mg/kg/day), is used to calculate the concentration of chemical in the mother's tissue. The maternal chemical concentration (C_{mother} in mg/kg-body-weight) at time T is:

$$C_{mother} = \int_0^T me^{-kt} \, dt$$

where the mother is exposed to the chemical from time $t = 0$ to time $t = T$ (in days). The general solution to this equation is:

$$\int_0^T me^{-kt} \, dt = \frac{me^{-kT}}{-k} - \frac{me^0}{-k} = \frac{me^{-[\ln(2)/h]T}}{-k} - \frac{m}{-k} = \frac{me^{-[\ln(2)][T/h]}}{-k} + \frac{m}{k}$$

$$= \frac{m\,(0.5)^{T/h}}{-k} + \frac{m}{k} = [1 - (0.5)^{T/h}]\,\frac{m}{k}$$

[1] U. S. EPA. *Human Health Risk Assessment Protocol for Hazard Waste Combustion Facilities.* EPA 530-R-05-006, September 2005.
[2] ATSDR. *Toxicological Profile for Polychlorinated Biphenyls.* November 2000.
[3] Allan H. Smith. Infant Exposure Assessment for Breast Milk Dioxins and Furans Derived from Waste Incineration Emissions. *Risk Analysis,* Vol. 7, No. 3. 1987.

Substituting again for $k = \ln(2) / h$,

$$C_{mother} = [1 - (0.5)^{T/h}] \frac{mh}{\ln(2)}$$

If the exposure period of the mother to contaminated fish (T) is equal to the chemical half-life (h) of 7 years for PCBs, then the chemical concentration in the mother's tissue is:

$$C_{mother} = 0.5 \frac{mh}{\ln(2)}$$

This result is relevant for the uncertainty evaluation. If the mother is exposed to PCBs for 7 years prior to breast feeding, the PCB concentration in lipid tissue is one-half the value obtained assuming steady-state conditions.

If the exposure period of the mother to contaminated fish is equal to four half-lives ($T = 4h$ = 28 years), then the chemical concentration in the mother's tissue is:

$$C_{mother} = 0.94 \frac{mh}{\ln(2)}$$

The limit of $[1 - (0.5)^{T/h}]$ for large values of T (relative to the half-life h) is 1. Therefore, at exposure periods to the mother longer than the chemical half-life, a reasonably conservative assumption is that the chemical concentration in the mother can be approximated by:

$$C_{mother} = \frac{mh}{\ln(2)}$$

This equation is further refined by considering the fraction of the chemical stored in fat tissue (f_1) and the fraction of the mother's weight that is fat (f_2).

$$C_{mother} = \frac{mh}{\ln(2)} \frac{f_1}{f_2}$$

Substituting the symbol ADD_{mother} for m, and assuming that the chemical concentration in milkfat is equivalent to the chemical concentration in the mother's fat tissue, yields the equation for $C_{milkfat}$ shown in the main text.

$$C_{milkfat} = \frac{ADD_{mother}\, h}{\ln(2)} \frac{f_1}{f_2}$$

Reduction in Chemical Dose to Infant Over Time

The loss of chemical mass through breast feeding will reduce the chemical body burden in the mother, thereby reducing breast milk concentrations and dose to the infant over time. Reductions in human milk ingestion rate will also reduce the dose to the infant. To develop a default estimate of exposure over a year period of breast feeding, we decided to look at both chemical mass reductions and milk ingestion rate reductions at one-half year of breastfeeding. The median overall reduction in dose to the infant will be used as the parameter value for f_5 in the equation for chemical dose to infant.

Smith[3] provided a method for estimating maternal chemical loses from human milk secretions. If the maternal half-life from breast feeding is h_b, the corresponding rate constant is

$$k_b = \frac{\ln(2)}{h_b}$$

The value for k_b can be calculated by adding the rate constant without human milk loses, k, as discussed above, to the fraction of chemical lost in human milk per day (c):

$$k_b = k + c$$

Assuming that the daily intake of human milk (b in kg/day) is constant, Smith showed that c can be calculated by:

$$c = \frac{b}{W}\frac{f_1 f_3}{f_2}$$

The fraction of chemical lost in milk is the ratio of the daily secretion of milk (b) to the mother's body weight (W), taking into account the proportion of chemical in fat tissue (f_1 = 0.9), the lipid content of the milk (f_3 = 0.04), and the fraction of mother's weight that is fat (f_2 = 0.3). Although EPA's *Child-Specific Exposure Factors Handbook* shows that human milk ingestion rates are variable over time, they are approximately constant. The Combustion Guidance uses a value for b of 0.9 kg/day.

The equation for k_b can now be expressed as:

$$k_b = k + c = k + \frac{b}{W}\frac{f_1 f_3}{f_2}$$

Assuming that exposure to the mother (for instance from fish consumption) continues to occur during breast feeding, the milkfat concentration T days after the start of breast feeding is:

$$C_{milkfat(T)} = \frac{me^{-k_b T}}{k}\frac{f_1}{f_2} + \frac{f_1}{f_2}\int_0^T me^{-k_b t}\,dt$$

The first term in this equation covers the reduction of initial concentration due to both metabolism and breast feeding loses, and the second term covers the increase in concentration that occurs from continual maternal exposure to chemicals. As discussed in the section above, *m* is the maternal daily chemical intake rate. At birth, the chemical concentration is:

$$C_{milkfat(0)} = \frac{m}{k}\frac{f_1}{f_2}$$

Assuming a constant secretion of milk per day, the equation for $C_{milkfat(T)}$ can be used to calculate the relative reduction in chemical concentration at time *T* relative to the concentration at birth.

$$\frac{C_{milkfat(T)}}{C_{milkfat(0)}} = \frac{\left(\frac{me^{-k_bT}}{k}\frac{f_1}{f_2} + \frac{f_1}{f_2}\int_0^T me^{-k_bt}dt\right)}{\frac{m}{k}\frac{f_1}{f_2}} = e^{-k_bT} + k\int_0^T e^{-k_bt}dt =$$

$$= e^{-k_bT} + \frac{ke^{-k_bT}}{-k_b} - \frac{ke^{-k_b0}}{-k_b} = e^{-k_bT}\left(1 - \frac{k}{k_b}\right) + \frac{k}{k_b}$$

To calculate the relative reduction in dose to the infant at time *T*, we need to consider the reduction in human milk ingestion rate on an infant body-weight basis over time in addition to the reduction in chemical concentration. Whereas milk ingestion on a mass per day basis (*b*) remains relatively constant, milk ingestion on an infant body-weight basis (*b'* in ml/kg/day) declines over time as the infant grows. The same evaluation could be performed using infant body weight values. The relative reduction in human milk intake at time *T* relative to birth is:

$$\frac{b'_T}{b'_0}$$

By combining the relative reduction in chemical concentration with the relative reduction in milk ingestion rate, we can approximate the overall reduction in dose to the infant at one-half year relative to the starting dose:

$$\frac{C_{milkfat(183)}}{C_{milkfat(0)}}\frac{b'_{183}}{b'_0} = \left[e^{-183k_b}\left(1 - \frac{k}{k_b}\right) + \frac{k}{k_b}\right]\frac{b'_{183}}{b'_0}$$

The rate constant *k* can be calculated from the half-life of 2550 days for PCBs.

$$k = \frac{\ln(2)}{h} = \frac{0.693}{2550} = 0.00027 \text{ (day)}^{-1}$$

The rate constant k_b is calculated as follows using the equation derived above:

$$k_b = k + c = k + \frac{b}{W}\frac{f_1 f_3}{f_2} = 0.00027 \text{ (day)}^{-1} + \frac{(0.9kg/day)(0.9)(0.04)}{(66kg)(0.3)} = 0.0019 \text{ (day)}^{-1}$$

To approximate the human milk intake rate ratio, we can use empirical data from EPA's *Child-Specific Exposure Factors Handbook.* We will use the ingestion rate for 0 to 3 months of 150 ml/kg/day to approximate b'_0, and the ingestion rate for 3 to 6 months (110 ml/kg/day) to approximate b'_T at one-half year (T = 183 days). The resulting overall reduction ratio in dose is:

$$\frac{C_{milkfat(183)}}{C_{milkfat(0)}}\frac{b'_{183}}{b'_0} = \left[e^{-183(0.0019)}\left(1-\frac{0.00027}{0.0019}\right)+\frac{0.00027}{0.0019}\right]\left[\frac{110}{150}\right] = [0.75][0.73] = 0.55$$

The appropriate value for f_5 is 0.55 for PCBs or other chemicals with a metabolic half life of 7 years. Other chemical-specific values for f_5 can be calculated using the above equations.